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MONTANA ENERGY CONSERVATION PLAN

Working Paper No. 1

PLEASE RETURN
RESIDENTIAL ENERGY CONSERVATION

A report to the
Montana Energy Advisory Council

Prepared for

The Montana Energy and MHD Research and Development Institute, Inc.
Butte, Montana

By

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1.0 RESIDENTIAL SECTOR

1.1 Introduction

The application of energy conservation measures in the home is the least costly, most readily available, and most effective means of meeting our energy needs. In this section, patterns of energy flow through residences are described and analyzed. A number of conservation measures altering these patterns will be considered. Fossil fuel and electricity use can be reduced by using these fuels more effectively, by using available renewable energies such as solar and wind, or by redefining the nature of the energy-using tasks which take place in residences.

Consumption of fossil fuel and electricity for typical Montana residences has been calculated. Conservation options, centered on reducing fossil fuel and electricity consumption in space heating, water heating, lighting and appliances, are applied to a prototypical residence. Fuel savings for this residence, and overall savings in the residential sector given a range of implementation strategies, are determined.

Our definition of residential sector fossil fuel and electricity usage is somewhat arbitrary and is being restricted

to those flows that can be monitored by gas or electric meters at the house, or purchase of liquefied gases and heating oil (metered at distribution point or truck). If our criteria was what fuel and electrical flows are determined by decisions made at a household level, then family-car gasoline usage, manufacturing of household items, water delivery, sewage and waste disposal, and food production would be integrated in the residential sector as they have been in other studies (Davis, 1975; Odum, 1974; Transition, 1975). The reader is cautioned not to allow our division of energy use to define the problem of conserving fossil fuels and electricity. How the problem is defined often determines who thinks it is their perogative to solve it, what kinds of solutions are visible, and what methods are acceptable.

1.1.1 Proportion of Montana Energy Use

In 1970 the residential sector accounted for 16 percent of total Montana energy consumption (FEA, 1976). Table 1.1 presents the breakdown of fuel use in the residential sector.[1] Table 1.2 presents this breakdown by end use, and Figure 1.1 presents the thermodynamic breakdown.

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[1] Some residential users are metered as commercial; this would account for an additional 15,600 housing units (U. S. Census Bureau, 1970). It would add about 1.8×10^{12} BTU/year to the totals given in Table 1.1.

Table 1.1

1.1.2 Breakdown by Fuel Use

	% of sector	% of fuel	x 10^{12} BTU's/year
natural gas	69	28	25.6
electricity	14	17	5.2
liquified gas	10	56	3.8
distillate oil	7	13	2.5
	100		37.1 x 10^{12} BTU/year

Source: FEA, 1976 (1970 fuel consumption)

1.1.3 Breakdown by End Use

In the residential sector there are four main categories of end use:

1. Space heating
2. Domestic water heating
3. Lighting
4. Appliances

Table 1.2

End Use by Fuel Use in the Residential Sector

	natural gas		electricity		other	Total	
end use	x10^{12}BTU/yr	%	x10^{12}BTU/yr	%		x10^{12}BTU/yr	%
space heating	20	78	.8	15	5.5	26.3	71
water heating	4.7	19	1.0	19	.6	6.3	17
lighting			.8	15		.8	2
appliances	.9	3	2.6	50	.2	3.7	10
TOTALS	25.6	100	5.2	99	6.3	37.1	100

Source: Wheeling, 1976 (1970 consumption)

1.1.4 Breakdown by Thermodynamic Type

The tasks or end uses of energy are broken down by thermodynamic type in order that we may see what quality of energy is necessary to accomplish these tasks. With the large percentage of task energies requiring a low temperature quality heat, it is clear that the present use of high quality liquid or gas fuels or electricity for these tasks is inherently wasteful (see Appendix II).

1.1.4.1 low temperature (space heating, water heating, clothes drying)
89%, 32.9 x 10^{12} BTU/year

1.1.4.2 medium temperature (cooking)
4%, 1.5 x 10^{12} BTU/year

1.1.4.3 high temperature
0%

1.1.4.4 electricity (appliances)
7%, 2.5 x 10^{12} BTU/year

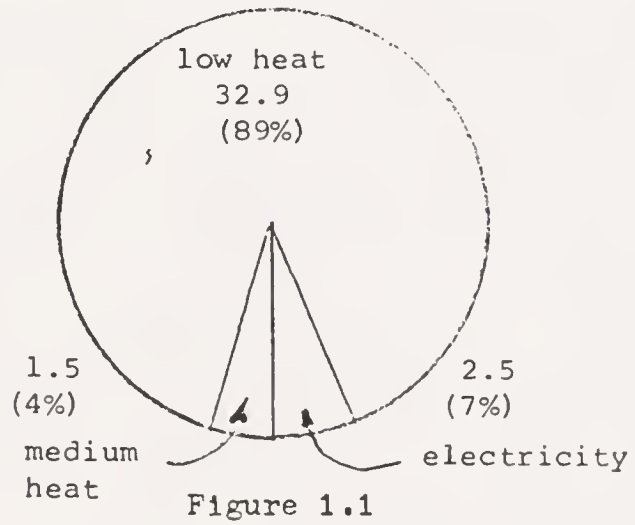


Figure 1.1

1.2

We who live in the "housing units" ("single family" houses, apartments, mobile homes, duplexes, etc.) do not value the fossil fuel or electrical inputs, but rather the work these inputs accomplish. It would be better if this work could be accomplished by using less fuel or electricity or none at all. This could be accomplished in three general ways:

1. The fossil fuels and electricity used to perform this work can be used more efficiently.
2. The tasks themselves can be redefined. For example, if it is seen as appropriate to wear insulated clothing inside during winter months, interior ambient temperature can be reduced; thereby decreasing the need for heat energy.
3. At the site of the residence, environmentally-available energy flows could do useful work (e.g., solar radiation, if allowed access to interior spaces, can provide warmth that might otherwise be provided by a gas-fueled furnace).

The following section will examine the fuel and electrical flows through residences, and suggest options and strategies whereby the necessary work can be accomplished with reduced fuel and electrical consumption.

1.2.2 Energy Using Tasks

The tasks of providing a warm living space and hot water at the tap consume most (88%) of the fuels and electricity in the residential sector. Table 1.3 summarizes the percentages of Montana

households which own specified appliances. These percentages are called saturations.

Table 1.3

Appliance Saturations in the Residential Sector

	natural gas %	electric %	distillate oil %	liquefied gas %
space heating	70	4	14	9
water heating	62	30		5
lighting	0.3	100		
cooking	25	66		7
refrigeration		99		
freezing		54		
clothes drying	3	52		
clothes washing		85		
television:				
B&W		46		
color		60		
air conditioning:				
room		7		
central		2		
dishwashing		30		

Source: Wheeling, 1976; U.S. Census, 1970

Given these saturations, an "average" residence in Montana could be expected to have natural gas space and water heating. Electric cooking and those electrical appliances with saturation greater than 50%(as given in Table 1.3) would also be found in the average residence.

1.2.3 Energy Model

In order to analyze how energy is used in the residential sector, a model of energy use within "characteristic residences" has been developed. This has been described first by an Energy Balance Equation for space heating requirements in a Montana residence; second, by a similar equation for water use; and third, by appliance and lighting use in average Montana residences.

1.2.3.1 Space Heat Equation:

$$G_a + G_s + G_o + G_h = L_w + L_s + L_a$$

where:

L_w = loss through windows

L_s = heat loss through roof/ceiling, walls, doors & floor

L_a = heat loss through infiltration

G_s = solar gain through windows

G_o = heat given off by occupants

G_a = heat given off by appliances

G_h = heat energy supplied to living space

(Bliss, 1976; ASHRAE, 1972.)

Since G_h describes the heat energy energy supplied to the space, we must multiply by the efficiency of the furnace to find the fuel input, thus:

$$G_h = eG_f$$

where: e = efficiency of heating system (first law)

G_f = the BTU content of fuel delivered to the furnace.

Now, solving for the furnace fuel requirements:

$$eG_f = L_w + L_s + L_a - G_s - G_o - G_a$$

1.2.3.2 Hot Water Equation:

$$G_p = L_f + L_b + G_w$$

where: L_f = Flue and pilot losses

L_b = heat transfer through tank wall and pipes to unheated area

G_w = heat content of water at end use

G_p = BTU content of fuel used to heat water

(efficiency is subsumed in flue losses term)

Hot water usage has been determined by Mutch (Dole, 1975) for the average home. The heat content of this water is multiplied by 1.14 to account for the colder groundwater temperature prevalent in Montana. Using the Hot Water Equation, the yearly energy consumption for an average Montana home has been estimated at 28.7×10^6 BTU. This assumes 20% flue and pilot losses and 75^o temperature difference between tank and basement. The input water is assumed to be 45^o on the average (Dole, 1975).

1.2.3.4 Fossil Fuel and Electricity

Fossil fuel and electricity for the other residential sector tasks are assumed for the average residence as follows:

Table 1.4

task	BTU equivalent	electrical use
	x 10^6 BTU/year	KWH/year
lighting	3.8	1100
cooking	4.0	1175
refrigeration	2.5	730
freezing	4.1	1195
clothes washing	.4	100
color t.v.	1.7	500
clothes dryer	3.4	990
	19.9	5790

Source: Wheeling, 1976

1.3 Characteristic Residences

The hot water, appliance, and lighting usage is assumed to be constant for different housing types. The space heating requirement, however, varies widely for different housing types. Five characteristic residences are conceptualized and analyzed. A survey of state and local building-code officials, winterization-program officials, mobile home dealers, and insulation and building contractors was conducted to determine physical characteristics which affect heat gain/loss in Montana residences. Characteristic residences have been developed which represent typical single-family houses built before 1940; this included the "average" home, new construction, mobile homes, and multi-family residences.

The 1970 Housing Census of Montana gives the following data distribution of housing units:

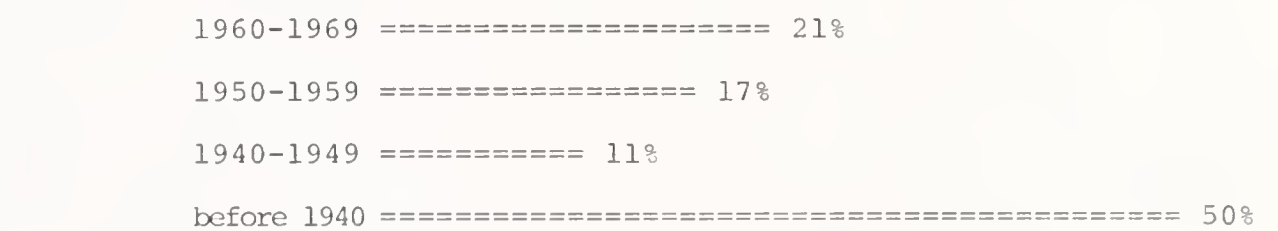


Figure 1.2

Age Distribution of Housing in Montana

Source: U. S. Census, 1970

Houses greater than 37 years old represent a major segment of building stock in Montana. The distribution of housing, according to the 1970 Census, between single-family, multi-family and mobile homes, is as follows:

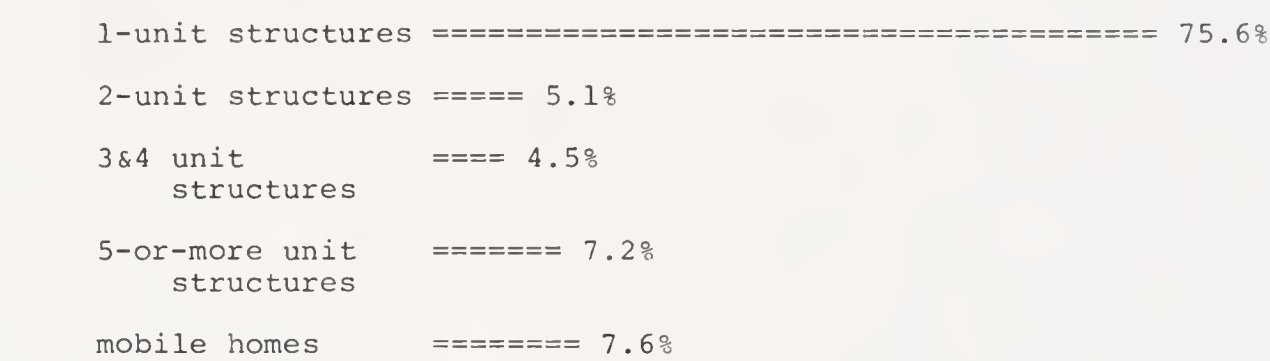


Figure 1.3

Housing Types in Montana

Source: U. S. Census, 1970

Mobile homes account for a substantial fraction of new housing, as do houses greater than 1,500 square feet.

The prototypical house used in our analysis represents the average Montana single-family residence in two respects. Typical residence construction was determined from the survey, including insulation levels, single pane/double pane glass areas, air infiltration, floor area, building materials, and house type. Second, the energy use of the prototypical house was compared with data on residential fossil fuel and electricity use (FEA, 1976; Wheeling, 1976; Dole, 1975). The physical characteristics of the prototypical house were calibrated to match the average fossil fuel and electricity use for space heating in the residential sector.

The fossil fuel and electricity use per residence for each task in this average house, multiplied by the number of buildings, represents the fossil fuel and electricity use of all single-family residences combined. Adding use in multi-family and mobile homes gives total residential sector fossil fuel and electricity use. Characteristics of the prototypical single-family house follows below in Table 1.5. Characteristics for the other residences are presented in the appendix.

Applying the Energy Balance Equation to these characteristic residences yields their heat loss and gain and fuel use, as below:

	Lw	La	Ls	Go+Ga	Gs	Gh	Gf
average	17	37	82	28	8	98	154
pre 1940	15	47	115	28	6	143	220
new	21	47	63	28	10	93	143
mobile	11	16	46	19	2	52	74
multi.	15	35	27	19	8.2	50	77

Figure 1.4

Heat Gains and Losses of Typical Residences

(given in BTU x 10^6/year)

1.4 Conservation Options

Four end-use categories of conservation techniques or technologies (options) are considered: space heating, water heating, lighting, and appliances.

In the following tables, conservation options are applied to the average prototypical single-family residence. Water heating, lighting, and appliance conservation options are assumed to operate in a like manner on all residential types.

Table 1.5 summarizes the assumptions applied to the prototypical residences to meet the requirement or standards suggested. Table 1.6 summarizes the fuel use characteristics required for space heating. Table 1.7 summarizes energy and fuel requirements for hot water, lighting, and appliance use.

Table 1.6 indicates that by providing more insulation for houses, energy use can be cut by 27-66%. By adding south-facing windows, this savings can be further increased. Energy used for appliances, lighting, and water heating can be reduced by 40% according to Table 1.7.

Table 1.5

Characteristics of Prototypical House
With Conservation Options

	Prototypical House	Option 1	Option 2	Option 6	Option 7
Floor Area	1200	1200	1200	1200	1200
Glass Area (% of floor area	10%	10%	10%	12%	16%
Window Distribution	even	even	even	south facing	south facing
"U" Factors:					
Ceiling/roof	.1	.05	.03	.03	.03
Walls	.1	.1	.065	.065	.03
Floor	.3	.08	.05	.05	.03
Doors	.65	.65	.3	.3	.3
Windows	.65	.65	.54	.3	.3
Infiltration (Air changes/hr.)	1	.9	.5	.5	.3
Burner Efficiency	.65	.65	.65	.65	.7
Occupant Heat Gain	26,000 BTU/day	26,000	26,000	26,000	26,000
Appliance Usage	68,000 BTU/day	68,000	68,000	68,000	68,000

Table 1.6

Energy Use for Prototypical Houses
(x 10^6 BTU/year)

Prototypical House	Base	Option 3	Option 4	Option 4a	Option 6	Option 8
Fuel Input	153	128	143	67		114
Heat Losses	137					
Heat Gains	36					
Option #1						
Fuel Input	112	94	104	49	88	83
Heat Losses	109				102	
Heat Gains	36				45	
Option #2						
Fuel Input	52	40	50	23	43	33
Heat Losses	70				73	
Heat Gains	36				45	
Option #7						
Fuel Input	0*					
Heat Losses	45					
Heat Gains	67					

*Excess Heat Vent Out

Table 1.7

Energy Use for Appliance & Hot Water
(x 10^6 BTU/year)

Prototypical House	Standard	Option 10	Option 11
Hot Water	28.7	11.0	11.0
Appliances & Lighting	20.0	20.0	18.0

1.4.1 Option I

The American Society of Heating, Air Conditioning and Refrigeration Engineers (ASHRAE) has published a set of conservation standards (ASHRAE 90-75). These standards have been adopted as minimum building standards in many states and cities. While they have achieved some notoriety, nonetheless they represent standards well below the economic optimum for the Montana climate. Option I applies these standards to the prototypical house. The wall and window requirements of ASHRAE 90-75 are already met by the prototypical house: the roof would require an additional 3-5" of insulation; the floor would require the addition of 3.5" of batten insulation; and some caulking would be necessary to meet the infiltration requirements. New standard construction meets these requirements.

1.4.2 Option II

The climate in Montana allows a much greater level of insulation than suggested in ASHRAE 90-75 to be cost effective (Peterson, 1974: Bliss, 1976: EMR, Canada, 1976; Owens/Corning, 1976). Option II applies more rigorous standards which are cost effective in Montana's climate. These standards include the addition of 1-2" of insulation to the walls; storm windows or double glazing; 8" of insulation to the ceiling; 6" of insulation to the floor; and extensive caulking, weatherstripping, and higher construction standards to reduce cracks and cut drafts and infiltration.

These measures do not represent the maximum energy savings possible. Indeed, under many circumstances, more stringent standards would be appropriate and cost effective. These would include insulated window shutters, further reduction in infiltration losses, and additional insulation.

While these conservation measures have been applied to the average house, measures that can be reasonably applied to the variety of housing in Montana will differ from house to house. For instance, stringent conservation standards could be applied to new construction while less extensive measures may be required in remodel situations. Remodeling homes which do not have adequate insulation is the most cost justified measure. However, as more new and existing homes are adequately insulated, fossil fuel and electricity savings due to increased insulation will decrease proportionately.

1.4.3 Option III

All heat losses used in this analysis assume an interior temperature of 70°F. As greater amounts of insulation are added to houses, temperature stratification (the tendency for air temperature to be higher at the ceiling) is markedly decreased; also, floor temperature (in contact with one's feet) increases, thereby increasing perceived thermal comfort. The reduction of air infiltration and accompanying drafts has a similar effect. These effects, combined with use of an automatic setback device, could lower average temperature to 63-68°F (65°F is assumed).

1.4.4 Option IV

1.4.4.1 Furnace Efficiency

In this option, the furnace and burner are upgraded to enhance the overall efficiency of fuel use. This can be accomplished by regular cleaning and maintenance, by more careful matching of furnace size to the heat demands of a house, by adding flue heat recovery devices, and by insulating hot air supply ducts.

1.4.4.2 Heat Pumps

An additional method to enhance fuel use would be to install heat pumps. These are substantially more expensive than standard residential furnaces; however, they deliver heat at two to four times the efficiency of a forced air oil or gas furnace. They use electricity to extract heat from the outside, upgrade it, and deliver it to the interior.

In Montana's climate, heat pumps would operate at reduced efficiency during part of the year due to the extreme cold. This, however, would be compensated for by very high efficiencies in the spring and fall. As a result, the heat pump is assumed to deliver an operational efficiency (Coefficient of Performance) of 1.5 during a Montana heating season. Coefficient of Performance (COP) is defined as the ratio of the heat output of the heat pump to the electric input. This ratio is dependent on the difference in temperature through which the heat is upgraded.

An earth-tempered heat pump, using the ground as an energy source, could operate during the winter and have an average operational efficiency of 2.5.

1.4.5 Option V

Not all rooms in a house are in use during the day. It is possible to reduce fossil fuel and electrical (ff/e) consumption by lowering the temperature in those rooms not being used if zoned heating controls (dampers, valves, thermostats) are properly located. As interior walls are not usually insulated from heated rooms, heat will transfer from the heated rooms, but so slowly that an overall ff/e use reduction is possible. This option could reduce ff/e use in the house by about 30 percent over a full heating season (S.O.M., 1976).

1.4.6 Option VI

This option addresses the heat loss and gain of the windows in houses. Windows lose heat because of their relatively poor thermal transfer characteristics. Windows allow sunlight and thus heat energy to enter the house. Under normal circumstances, the windows lose more heat than they gain; however, by relocating the windows to the south side and removing them from the north side (where no sun falls), a substantial improvement would be realized. In addition, the windows could be fitted with night shutters made from 2" styrofoam to substantially reduce night losses through the windows. In new construction, the additional cost for this option is zero. In remodel construction, this would involve more expense as windows would have to be relocated or removed.

For our prototype house it is assumed that there are 100 sq. ft. of windows on the south side, 25 sq. ft. on each of the sides, and no north windows (see Appendix III for other solar options).

1.4.7 Option VII

Houses that are built above the ground are subjected to the extremes of Montana Climate. With low temperatures and high winds, heat is easily conducted across house surfaces and blown out small cracks. Ground temperatures are much more moderate than air temperatures (the fact that basements stay warmer in winter than other unheated spaces and cooler in summer than un-air conditioned houses is an example of the moderating influences of the earth) (see Figure 1.6). By placing buildings in the earth, or berming the north wall, or adding a sod roof, the earth's moderating influence can be put to use in interior temperature control (Figure 1.5). Also, air infiltration is greatly reduced in appropriately designed earth-covered buildings due to the nature of the wall construction. Variations in ground temperature decreases with depth, and fairly deep ground temperatures are out of phase with air temperatures, so that the earth is cooler in summer and warmer in winter. Heat given off by the appliances and occupants is almost sufficient to heat the building, and the solar heat input is more than adequate.

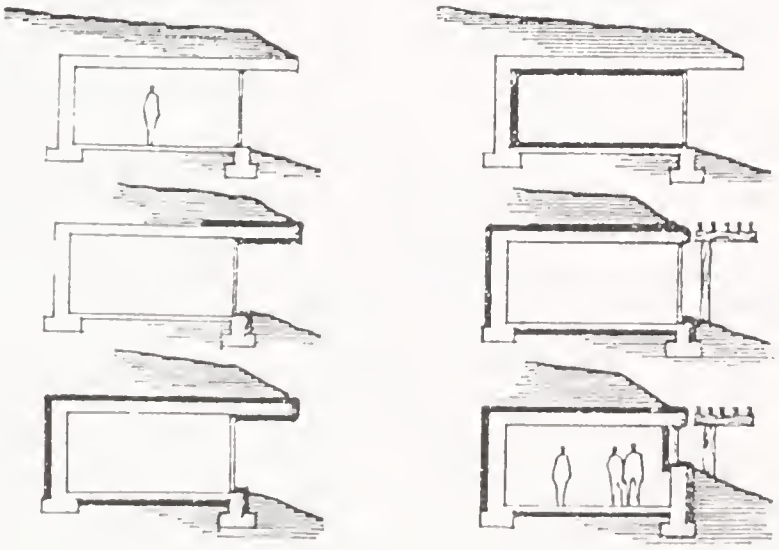
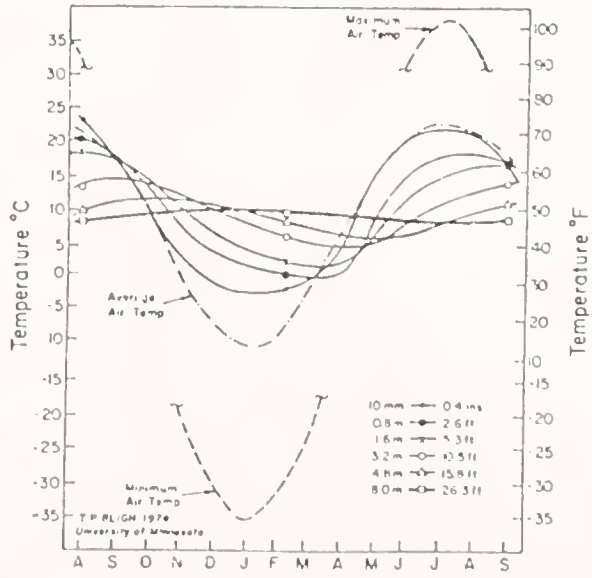


Figure 1.5



Average monthly temperature variation with soil depth near St. Paul, Minnesota (data from Reference 6 and E. Bowers, University of Minnesota).

Figure 1.6

1.4.8 Option VIII

This option involves a voluntary reduction in interior temperature below conventional practice. This would necessitate wearing more clothing. An average daytime temperature of 66°o and nighttime temperature of 60° is assumed.

1.4.9 Option IX

This option examines the possibility of small houses. This trend already is prevalent with the increasing number of mobile homes (40 percent of the new homes in Great Falls are mobile homes). Reducing square footage from 1500 sq. ft. to 1000 sq. ft. can reduce energy consumption by 50 percent. This also could include greater numbers of multi-family dwellings. The multi-family dwelling uses 50 percent of the energy that an average detached dwelling uses.

1.4.10 Option X

A number of possible conservation measures are available for hot water heating:

1. Insulate hot water tank
2. install water flow constrictor devices in shower heads (bathroom faucet also)
3. wash clothes in cold water
4. increase recovery time on hot water tank
5. insulate hot water pipes
6. add damper to gas flue
7. turn down hot water temperature to 120-130° F
8. install point-of-use hot water heaters (dishwashers have them)

Four measures are considered in greater detail:

1.4.10.1 Insulate tank to R = 5 (ASHRAE standards 90-75). Presently, only electrical hot water tanks are so insulated to this level.

1.4.10.2 Insulate tank to R = 15 level, either by wrapping present electrical tank with R = 11 insulation in retrofit application, or by requiring manufacturers to add more insulation.

1.4.10.3 Use of constrictor head on showers. With about 49 percent of fossil fuel and electricity used to heat hot water for showers or baths. dropping total water flow from 6-8 gallons per minute down to 3 gallons/minute represents a substantial reduction in fossil fuel and electricity use.

1.4.10.4 Cold water clothes wash. About 29 percent of hot water used is for clothes washing.

Table 1.8

Ff/e Savings per Hot ater Heater (40 gallons)

x 10^6 BTU's/year

OPTION	L_f	L_b	G_w	G_f	Cost
STANDARD	5.8	9.4	13.5	28.7	
I	5.8	5.6	13.5	24.9	$10
II	5.8	2.0	13.5	21.3	$8/electric $34/gas
III	4.4	2.0	10.2	16.6	$5/shower
IV	2.7	2.0	6.3	11.0	None

1.4.11 Option XI

This option addresses fossil fuel and electricity use by the appliances and lighting throughout the house. It is assumed that a 10 percent reduction in fossil fuel and electricity use by appliances and lighting is possible through a number of measures. Conservation options for lighting include lowered lighting needs (ASHRAE 90-75 standards have been interpreted by Arthur D. Little, Co. to reduce residential design lighting levels by 20 percent); more task lighting; and turning off lights when not in use (A.D.L., 1975). The American Association of Appliance Manufacturers has pledged to increase appliance efficiencies within the next few years. Other appliance conservation measures include reduced usage, the dropping of "convenience features," and reducing the number of small electrical appliances within the home.

1.5 Economic Impacts of Conservation Options

The impact of conservation in the residential sector would include both increased capital costs of residential structure and appliances and increased employment in the production of this capital. Table 1.9 summarizes these impacts. The cost figures assume a life cycle of 30 years, an interest rate of 9%, and an inflation /fuel escalation rate of 6%. The costs are expressed on $/mmBTU for fuel and electrical savings over the economic life of the capital. The employment is expressed in person/days and derived from total initial capital costs. These are direct employment figures for jobs created in the state of Montana by each option; jobs created elsewhere are not included. The indirect employment impact could be three to four times the direct employment impact. As this is very difficult to quantify at this stage, these indirect impacts are not presented.

The principal impact of an energy conservation program in the residential sector is the fact that the use of conservation can obviate the need for new and expensive plants. These plants require 30 years investment and extensive infrastructure in design, construction and operation. The cost of electricity averages between $6 and $8 per million BTU's. Similarly, the cost of new gas resources is approaching $2/million BTU's. When compared to $.45/million BTU's in a residential conservation strategy, it appears that the obvious investment should be in conservation. Furthermore, this investment will pay off in under ten years, where major capital investments are amortized over 30-40 years.

Table 1.9

Fossil Fuel and Electricity Savings, Costs and Employment per Residence for Various Options

	x 10^6 BTU/yr energy savings	capital cost	lifecycle cost/ mmBTU	employment person/days
Option I	42	350	.45	2
Option II[1]				
remodel				
easy	102	1040	.55	14
dificult	102	1840	.98	24
new	60	560	.50	6
Option III[2]				
average	26	85	.22	.8
better	12	85	.48	.8
Option IV[3]	11	100	.62	.1
Option VII	140	6000	1.70	85
Option X				
1.	3.8	10	.15	.6
2.electric	7.4	8	.07	.04
gas	7.4	34	.31	.2
3.	4.7	5	.06	.02

[1]1200 sq. ft., single-family residence, average insulation -- except new assumed to be at new construction standards.

[2]effectiveness on setback dependent on level of insulation; applied here to two cases -- average and better.

[3]applied to average house.

1.6 Environmental Impacts

The generation of electricity and the burning of fossil fuels have wideranging adverse environmental impacts. Conservation, by reducing the need for these activities, reduces their associate impacts. Conservation, when it entails the replacement of fossil fuel and electricity use with capital items, entails its own adverse impacts.

A number of materials used for insulation purposes (Styrofoam, fiberglass) are produced from fossil fuels and have indefinite life spans. Environmental degradation occurs in their production and after their use. Using costs per million BTU's as an indicator of adverse impact shows that the negative impacts of conservation are an order of magnitude less than those of increased fossil fuel and electricity production.

Given a sun-oriented architecture, we might expect to find changing patterns of residential planning, with south slopes being heavily favored. Earth-protected houses represent a drastic change from present housing practices. Developments consisting of earth-protected houses would be less conspicuous than traditional suburbs. With greater uncovered earth area, plant and animal biota would be encouraged. Occupants in earth-protected houses experience much reduced noise levels allowing the placement of these houses in less desirable urban locations, thereby reclaiming otherwise useless land. Through utilization of concrete and not wood, the impact on forested land is greatly reduced. Concrete production is energy intensive, so that the impact of reduced wood use must be measured against the impact of increased concrete use. A number of insulating materia

are known to have adverse environmental effects in their manufacture and use. Asbestos and polyurethane are highly toxic and expose workers to unwarrented dangers. These and other toxic insulation materials should not be used.

In spite of the short payback periods for energy conservation measures, Montanans are not remodeling their houses at a substantial rate. If a higher rate of remodeling is required, the costs of fossil fuel or electricity could be increased to force homeowners to insulate their homes. Another alternative would be to provide a subsidy to homeowners insulating their homes. Earth-protected houses have a considerable first cost penalty; to encourage their construction, new mortgage instruments may be required. Conservation entails stiffer first costs, and with many Montanans presently priced out of the housing market, conservation will only add to their woes unless reduced fuel bills can be properly accessed by lenders.

1.7 Energy Conservation Strategies

A number of measures can be taken by state agencies that will encourage conservation efforts among citizens and businesses. In order to assess the effect of these measures, current consumption is projected into the future; given certain assumptions, the measures are applied, and a revised projected fossil fuel and electricity consumption is calculated. This is a projection, not a forecast. It does not take into account price changes that should occur and which would dampen demand in the future. Nonetheless, it gives us a reasonable base upon which to assess the effects of various conservation strategies.

Table 1.10 presents the base projected fossil fuel and electricity use.

Table 1.10 [1/] [2/] [3/] [4/]

Fossil Fuel and Electricity Consumption in Trillion BTU's for the Residential Sector

	natural gas	other fossil fuels	Electric I	Electric II[5/]	Total I	Total II[5/]
1976	28.4	7.5	6.9	23	42.8	58.9
1980	30.4	8.0	7.4	24.6	45.8	63
1985	33.1	8.7	8.1	26.8	47.8	68 5
1995	40.0	10.3	10.4	32.3	60.7	82.5
2025	66.3	17.1	16.0	53.4	99.4/136.8	

1/ Data developed by Terry Wheeling for natural gas and electricity consumption in 1974 or 1975 Whichever was reported latest was used. (Wheeling, 1976)

2/ Energy consumption of residential units in buildings of 5 or more units are added to commonly given residential energy consumption figures (Wheeling, 1976) to account for undercounting due to master metering of natural gas. (AGA, Dole 1975).

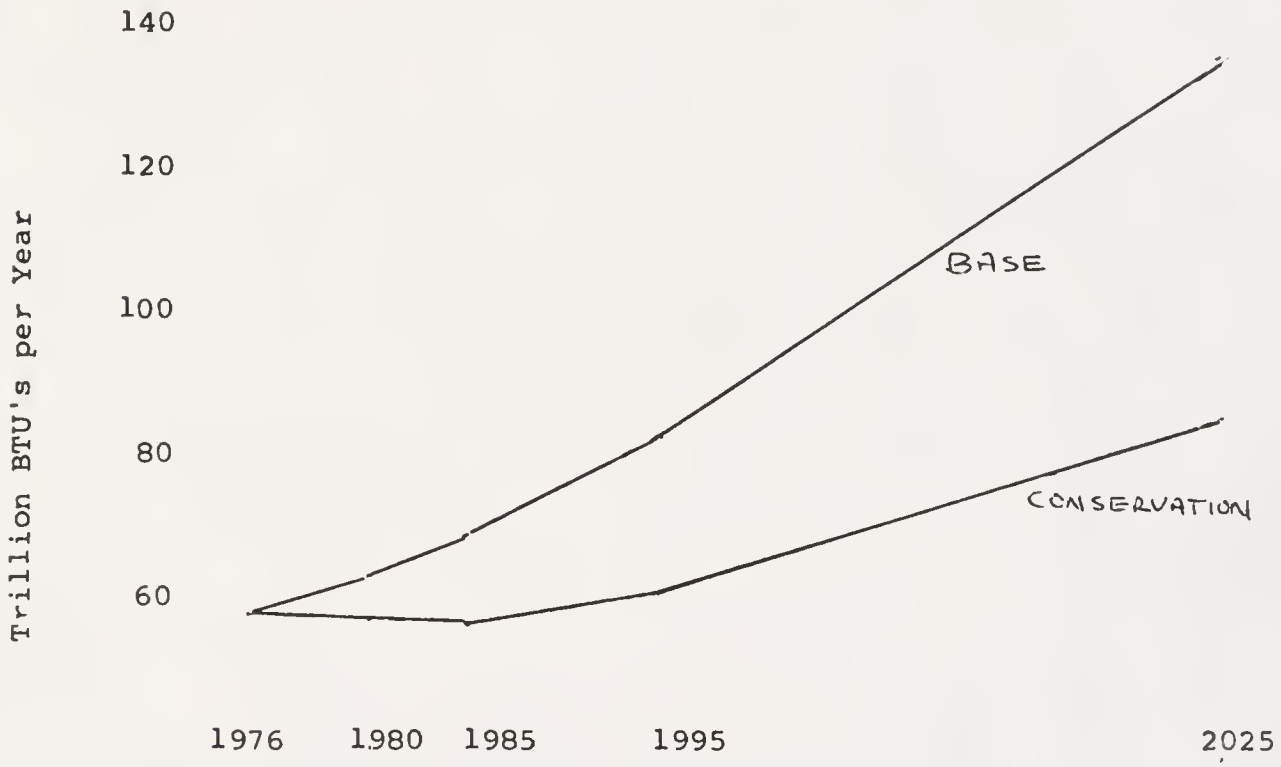
3/ Growth in housing units assumed to be 1.7%/year, based on MERDI energy demand model, Byron W. Jones. FEA's growth assumption for the west region is 3.4%/year. (Arthur D Little, 1976)

4/ Energy use per housing unit is held constant. While new homes are better insulated than the average, they may also be bigger or less well suited to utilize environmentally available energies, so the assumption of constant use was made.

5/ FEA mandates that end use electrical kwh be multiplied by a factor of 3.33 to account for losses at thermal generation plants. 90% of Montana s internal consumed electricity is hydro-based and this factor is not relevant. We have used it in order to comply with FEA mandate.

The proposed conservation measures will reduce this fossil fuel and electricity demand. If the strategies 1.7.2-1.7 8 are instituted, Table 1.11 and Figure 1.9 represent projected demand.

Figure 1.9



Residential Sector Projected Total
Fossil Fuel and Electricity Use

Table 1.11

Projected Fossil Fuel and Electricity Consumption
Given Conservation Strategies in Trillion BTU/year

	Natural Gas		Other Fossil Fuels		Electricity		Total	
	Base	Conservation	Base	Conservation	Base	Conservation	Base	Conservation
1976	28.4		7.5		23		58.9	
1980	30.6	26.8	8.0	7.2	24.6	23.0	63	57
1985	33.1	27.0	8.7	6.2	26.8	24.4	68.5	57.6
1995	40.0	26.7	10.3	7.1	32.2	26 9	82.5	60.7
2025	66.3	35.3	17.1	9.6	53.4	41	136.8	85.9

1.7.1 ASHRAE 90-75

ASHRAE 90-75 is adopted as an energy conservation building code and new and renovated houses are brought up to this standard.

Standard construction practices of new homes in Montana already meet this standard. Enforcement of ASHRAE 90-75 will reduce energy consumption in those new and remodeled houses which are not now built to this standard. Our methodology indicates a savings of 800 billion BTU/year by 1980.

1.7 1.1 The number of housing units, new, old and renovated is determined as follows: 1.7% growth rate in number of units; .5%/year remodel rate of existing units as of the thrid quarter of 1977, 1%/year renovation rates. The number of house units using fossil fuels or electric space and water heat is determined from 1970 Census of Housing, Montana. This applies to all strategies, unless otherwise noted.

1.7.1.2 No fuel substitution is assumed.

1.7.1.3 A 10% fossil fuel savings is used for space heating in new units over what would have occurred given current practices. This is 30% for renovations.

1.7.1.4 No reduction over current practices for electric heated homes is assumed, although 30% for renovations is assumed.

1.7.1.5 A 10% fuel savings in fuel used for hot water heating in new or remodeled units over average is assumed, although more for electrical is assumed.

1.7.1.6 A 10% reduction of electrical energy use over average for new units is assumed.

1.7.1.7 All renovations are brought up to code. This applies to all strategies.

1.7.2 Better Standards

Better standards (Option II) are applied to new and renovated homes through adoption of a stricter energy conservation building code. Projected fossil fuel and electricity consumption is expected to decrease by 2.1 trillion BTU/year by 1980 with this strategy.

1.7.2.1 Better standards allow a 50% reduction in heating energy use over the average house for both new and remodeled housing units. Table 1.6 shows a 67% reduction is possible, but as complete renovation may not be possible, and as new construction is already better weatherized than average Montana housing units, 50% is chosen as a conservative figure.

1.7.2.2 Water heaters are assumed to have R-15 insulation in new and remodeled housing.

1.7.2.3 A 10% reduction in electricity used for lighting is assumed for new units.

1.7.3 Education Program

Our study has shown that in almost every case conservation measures are less costly than comparable electricity or fossil fuel costs. Educational efforts to inform and motivate citizens can effect savings in both new and existing homes. To be effective and educational, effort must be well-coordinated.

Educational efforts are expected to save 3 percent of the projected base energy use in 1980 (S.O.M., 1976). This represents a 1.8 trillion BTU/year savings.

1.7.4 Weatherization

The homes of low and fixed income people are generally poorly built and badly insulated. By allocating $750,000 per year of state money, matching this 3 to 1 with federal money, 6,000 homes at $400/home can be weatherized. Two hundred billion BTU/year can be saved by 1980 with this program. Life cycle cost of the program is about $.50/mmBTU.

1.7.4.1 Housing units are assumed to use 180 million BTU/year to heat.

1.7.4.2 A 20 percent savings in heating fuel consumption is assumed. This represents experience with program to date.

1.7.5 Conservation Loan Program

While capital is easily available in substantial quantities to utilities and oil companies so that they can expand generation and production facilities, such capital availability is missing for the homeowner for energy conservation measures. To equalize the costs of capital for generation and conservation measures, low interest loans should be made available through the banking institutions of the state. By raising the assumed renovation

rate to 3 percent, the conservation loan program would result in a 1.2 trillion BTU per year saving by 1980 above that considered in the building code strategy.

1.7.5.1 Remodeled housing units are assumed to use 50 percent of the heating energy used prior to the remodel. This represents a standard less than the better standards and greater than ASHRAE 90-75 standards and is assumed to be economically justified.

1.7.5.2 Water heaters are assumed to be replaced or retrofitted with more insulation during renovation raising insulation values from R3 or R5 to R15.

1.7.5.3 This program accounts for 2/3 of the 3 percent renovation rate. This program is expected to cost homeowners about $29 million for renovations made through 1980 with payments spread out until 1990. It's lifecycle cost is about $.81/mmBTU to the homeowner.

1.7.6 Renewable Energy Tax Credit

The renewable energy tax credit would speed the utilization of solar energies by reducing their costs relative to existing fossil fuel costs. With rising fossil fuel and electricity costs, solar space and water heating will be cost competitive within a few years, and this measure, by encouraging the use of solar energy now, provides us with greater experience in solar energy so that it will be recognized as feasible later. It also encourages reduction in solar capital costs by providing an expanded market.

The tax credit will encourage solar hot water heaters and some space heating. Solar hot water heaters can provide 80 percent of the domestic hot water heating at a reasonable cost, about $1000 per heater. This is reduced to $600 per heater by the tax credit. Life cycle cost is decreased from $2.96 per mm/BTU to $1.77 per mm/BTU or about the costs of natural gas now. With a 1 percent per year remodeling rate, 6,400 homes in 1980 will have solar water heaters. This represents a savings in fossil fuel and electricity consumption of 180 billion BTU's per year. Costs to the state is $2.6 million by 1980.

1.7.7 Conservation Loan Program and Renewable Energy Tax Credit

Both of these programs will have an effect on the utilization of solar energy for space heating. The effect of these programs in terms of trillions of BTU's saved in space heating will be small by 1980. If 50 solar homes were built in the state by 1980, two billion BTU's would be saved in addition to those saved by the conservation measures which would have to be applied to these solar homes before the utilization of solar space heating is appropriate.

Assuming a cost of $6,000 per installation, the solar heating proportion of the 50 homes costs $300,000 at a cost of $8 per mm/BTU. The loan program cost to the state is $145,000 in income lost from reduced return on conservation loan program. The Renewable Energy Tax Credit reduces the initial cost of the solar heaters to $5,000 per unit. The state, then, would lose $50,000 in reduced tax income for housing units built by 1980. These measures reduce the lifecycle cost of solar space heating to $6.50 per mm/BTU.

1.7.7.1 A 50 percent solar heating system is assumed with an earlier 50 percent reduction over the average house heating needs through conservation measures.

1.7.8 Utility Rate Structure Study

Reforming utility rate structures to more adequately reflect both the cost of service and the long run incremental cost will encourage reduced demand. Assuming the utility rate structure study calls for conservation rates at the conclusion of the study in 1979, these new rates could effect consumption in 1980. Assuming a conservative reduction in projected electrical energy use in the residential sector of 1 percent, a 250 billion BTU per year savings could be achieved.

The use of energy price is a powerful mechanism for effecting consumption. Presently, electrical utilities are very resistant to state interference with their pricing mechanisms. Due to the fact that electrical rates are set on the basis of a specific rate of return on fixed capital assets, utilities resist conservation measures which do not increase their capital and eat into their cash flow. Therefore, it may be necessary, in order to carry out an effective conservation program, to permit the public or municipal ownership and/or governance of energy generation systems.

1.8 Projected Energy Savings for 2025

Projected energy savings for 2025 are 5×10^{12} BTU/year, somewhat less than we used in 1976 for the residential sector. Energy use is projected to be 86×10^{12} BTU/year, 43 percent greater than 1976 use. Clearly, measures other than conservation will be necessary to meet this demand. An accelerating renewable energy resource utilization capacity will be needed. By 2025, our calculations show only three trillion BTU/year will be provided by 2025 by any given renewable resource program to be enacted. Obviously, if solar energy is to supply a major share of the energy used in residences, its implementation will need to be accelerated.

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APPENDIX I

Characteristic House: Single-family Average

heated floor area (.75 width-to-length ratio)	1200 sq. ft.
glass, storm windows	10% U = .65 [2]
stories	1
ceiling/roof 3" loose fill insulation R total = 10	U = .1
walls-frame construction 2½" fiberglass insulation R total = 10	U = .1
floor, open joists furnace in basement 0" insulation unheated basement[1]	U = .3
doors 2 - 7'x3' no storm doors	U = .65
infiltration	1 air changes/hr.
furnace efficiency	.65

1. As a basement is assumed, temperature gradiant across floor is not as great as across wall. Temperature at basement = 56°F during heating season (not including possible heat gain from furnace) (ASHRAE, 1972).

2. u = heat conductance across the building surface, btus/°F hr.

Characteristic House: New construction single family residence

heated floor area (.75 width to length ratio)	1500 sq. ft.
glass, double windows	12% U = .6
stories	1
ceiling/roof 6" loose fill R total = 20	U = .05
walls - frame construction 3½" fiberglass insulation R total = 14	U = .07
floor (no basement-crawl space) 3½" fiberglass R total = 12	U = .08
2-7'x3' no storm doors	U = .6
infiltration	1 air changes/hr.
furnace efficiency	.65

Characteristic House: pre 1940 house

heated floor area (.75 w to 1 ratio)	1000 sq. ft.
glass, storm windows	10% U = .7
stories	1
ceiling/roof 2" R total = 8	U = .13
Walls - frame construction 0" insulation R total = 3.5	U = .3
doors 1-7'x3' no storm doors	U = .65
infiltration	1½ air changes/hr.
furnace efficiency	.65

Characteristic House: Multi-family

heated floor area (.5 w to 1 ratio) 6 units @ 900 sq.ft./unit	5400 sq. ft.
glass, storm windows	12% U = .65
stories	3
ceiling/roof Rtotal = 19 fiberglass	U = .05
walls - frame construction 2½" fiberglass R total = 10	U = .1
floor, open joists furnace in basement	U = .3
infiltration	1 air change/ hr.
furnace efficiency	.65

Characteristic House: Mobile home per 1970

heated floor area (10 x 50)	500 sq. ft.
glass, storm windows	10% U = .65
ceiling/roof R total = 11	U = .09
walls R total = 7	U = .14
floor R total = 7	U = .14
door 1-7'x3'	U = .65
infiltration	1 air changes/hr.
furnace 1st law efficiency	.70

APPENDIX II

Efficiency

Throughout this study certain efficiencies for the operation of heat delivery systems are assumed. These efficiencies are defined as the ratio of the heat delivered to the occupied space to the heat content of the fuel burned in the furnace. Recently, a team of physicists has developed another definition of efficiency that focuses on the task to be accomplished, i.e. heating the space on a cold day, rather than on the device that accomplishes this task. By changing our focus, we are able to ask what is the most efficient means of heating this space as opposed to what is the most efficient furnace that can be used to heat this space?

When a fuel is burned, its energy content is released into the heated space and eventually into the atmosphere, and, space. This energy is not lost, but after the fuel is burned, it is no longer able to do useful work such as heating the house. While this is obvious, it points up a certain important concept: that of available work.[1] Available work, the potential of the fuel to do work, is consumed as the fuel is burned and is lost forever.

The second law efficiency, as the new concept of efficiency is referred to, is defined as: "the ratio of the least available work that could perform the task to the available work actually consumed in doing the job with a given device or system" (Ford, et al, 1975). Available work is proportional to the temperature difference between the atmosphere and the operating temperature of the device. A fuel burning at a high temperature (greater than 3500^{o}F) has a high available work. The work necessary to heat a house (move heat

across the relatively small temperature difference between outside and interior) is quite small. Therefore, the second law efficiency of a furnace is small (about 8 percent). "The use of a high quality flame, at site or power plant, to provide low-quality, low-temperature heat is a fundamental abuse . . ." (Ford, 1975).

Devices other than a furnace can provide heat to interior spaces; one of the more exotic devices is known as a window. Because a window allows solar radiation into the interior where it provides heat at room temperature, it can operate at 100 percent second law efficiency. Active solar collectors, because they operate at temperatures greater than the outdoor ambient temperature and because they experience heat losses separately from the heated structure, operate at less than 40 percent second law efficiency.

Solar energy has two very interesting properties with respect to its temperature: first, the sun operates at a very high temperature and therefore solar energy is of a very high quality, and second, solar energy is diffuse and, by concentration, can be brought up to any desired temperature. Therefore, it is possible to match solar energy precisely to the temperature of the task required, thereby providing for a high second law efficiency.

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1 "Available work = maximum work that can be provided by a system (or by a fuel) as it proceeds (by any path) to a specified final state in thermodynamic equilibrium with the atmosphere" (Ford, 1975).

APPENDIX III

SOLAR APPLICATIONS IN RESIDENCES

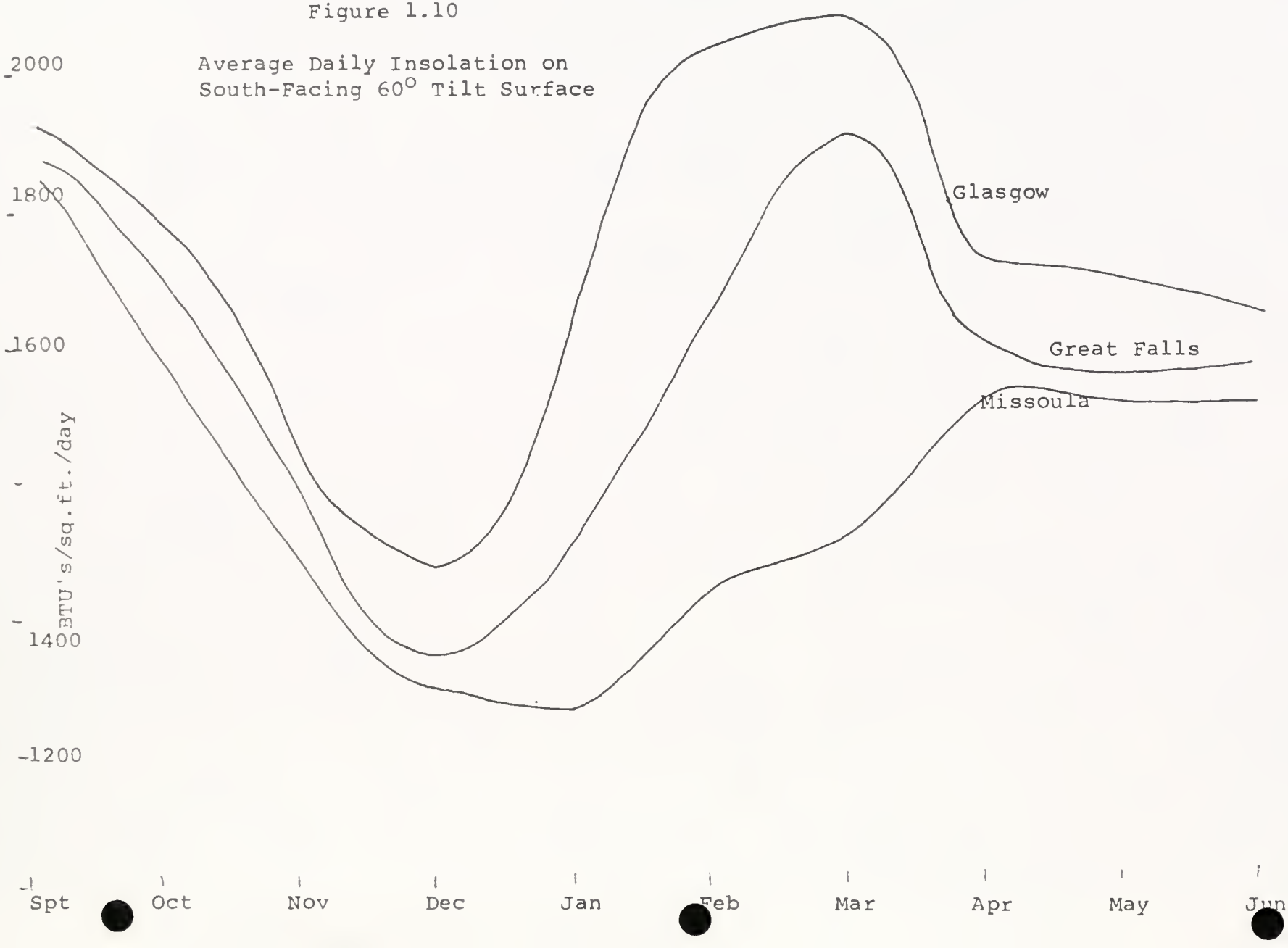
Previously, the utilization of south facing windows for light penetration into the interior space of the house has been demonstrated. Because of the low winter sun angle, sunlight on vertical southern exposures of Montana homes is easily admitted to the interior. Residences that can accept the sun and slow its eventual escape to the outside (either overnight, or for a week, or over a year) provide us with opportunities to live in northern latitudes with a minimum of environmental disruption.

Two meteorological stations, at Glasgow and Great Falls, collect solar data which, when correlated with other weather data can be used to give a picture of the Montana solar climate (see Figure 1.10). Except for some areas west of the Continental Divide, the solar climate of Montana fits within the range shown on the graph.

Two types of collection systems are used: passive and active. Passive systems were introduced and discussed in the Residential Conservation section, where heavy insulation combined with south facing windows increases solar heat gain to interior space. Passive home design or solar tempering begins with the addition of thermal

Figure 1.10

Average Daily Insolation on
South-Facing 60° Tilt Surface



mass within the structure to help moderate temperature fluctuations and to store incoming solar energy. Active systems employ the forced flow of a fluid or air over a specific collector area into a storage volume when sunlight is not available for use in heating or cooling.

The solar resource combined with a collection system gives a heat gain. For example:

A 60 sq. ft. flat plate collector at 45^{o} tilt operating at a yearly average of 50% efficiency produces 18×10^{6} BTU/year. This is about equal to the total water heating needs of the average Montana single family residence after conservation. Not all of this heat could be utilized, as some is thrown away in the spring and summer, and not enough will be collected at certain times in the winter.

A 300 sq. ft. flat plate collector at a 60^{o} tilt, operating at 30% efficiency during the heating season produces 28 million Btu's between October and April (see Figure 1.10). This is about 70 percent of the heat that is needed to heat the average Montana single family residence fitted with better insulation and south facing windows (see Table 1.6, Option 2 and 6). On the average solar day in December, the total heat loss for the home is 300,000 Btu's, and the collector will produce 100,000 Btu's providing 30 percent of the heating requirements.

As can be seen from the above numbers, the problem of gathering solar energy for low temperature space and water heating is obviously feasible if conservation efforts are first incorporated. Several options for solar energy application to residential structures are considered.

Proposed Solar Options

1. New construction, active and passive systems
2. Domestic water heating
3. Solar remodeling of existing structures
4. Photovoltaics in residential applications

The field of solar technology is experiencing a great deal of activity, and the possible schemes for carrying out the above solar options are numerous. Solar space and water heaters are commercially available, and many architects and engineers are presently designing solar installations. The design and technology possibilities available for the proposed solar options are outlined below.

1. New Construction:
    a. Passive solar house design
    b. Active solar system with solar panels tilted for winter sun or mounted vertically with reflectors to enhance performance
    c. Annual cycle energy system with panels tilted for summer collection and year-round storage.

d. Solar assisted heat pumps

2. Domestic hot water heating in either retrofit or new construction can be handled by a number of techniques:
   a. Passive, thermosyphon systems using either flat plate or vertical cylindrical collectors,
   b. Active flat plate collectors,
   c. Active tracking concentrators of the linear focus type,
   d. Active or passive stationary concentrators with seasonal adjustment,
   e. Heat exchangers incorporated inside the storage tank on active solar space heating systems.

   The technology is well-advanced, and presently there are over 100 manufacturers of solar hot water heaters.

3. Solar remodeling, basically an energy conservation retrofit with adjustments for increasing solar gain, provides a great opportunity to reduce the use of fossil fuel and electricity (ff/e) in the existing housing stock. Considering that growth in the residential sector is only 1-3 percent a year, the most effective ff/e reduction can be accomplished on existing housing. This remodeling of existing structures includes superior insulation, increased south facing windows with night shutters, and the addition of a solar greenhouse to the south side of the house.